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THE AUTOMOBILE HEADLAMP

A Study of the Beam Distributions Needed for Motor Vehicle Driving Lights

By J. H. NELSON, Ph.D., A.Inst.P. *(Fellow)*

(The Joseph Lucas Research Laboratories)

(Paper read on Tuesday, December 12th, 1944)

ABSTRACT: The beam requirements for the three principal conditions under which a headlamp must function, namely, (a) on the open road, (b) when passing, and (c) in fog, are examined and tentative specifications proposed.

Introduction.

The purpose of this paper is to describe the scientific background to the problems encountered in the design of motor-car headlamps. To achieve this, the conditions under which the motorist requires to see will be described in some detail, and from these conditions it will be possible to indicate the type of illumination most likely to be of service. There are three major cases to be considered, namely:—

(a) the open road driving beam, where only one vehicle has to be considered,

(b) the case of two vehicles passing, both of which have lamps, and

(c) the problem of movement in fog.

It is proposed to limit the discussion of the headlamp problem to these three cases only, and to deal with each in turn.

The case of the open road is probably the most instructive, as the design, not only of the beam distribution but also of the technical details of the actual headlamp equipment, can be based on deductive arguments from lighting experience and optical theory, and, moreover, the results so obtained are capable of application in practice. The principles of the design of the open road driving beam are, in fact, extremely simple, and this, in consequence of, rather than in spite of, the apparent complexity of the problem of having to illuminate a continually changing scene.

Whilst the case of the passing or anti-dazzle lamp and fog lamp present many points of similarity both in beam design and as a problem in vision, there are significant points of difference which must not be forgotten. In both these cases the performance of the human eye requires very careful examination and study. The design problems become far more complex than the open road case, but not so complex as to excuse some of the extravagant misconceptions that exist about both problems.

To remove some of these misconceptions, some space will be devoted to describing exactly what happens (a) when two cars pass and (b) when one tries to see through fog. Such analyses are extremely valuable in providing data for the design of what up to the present have been very imperfect solutions to the problems. It will be shown that an ideal solution is not possible, at the moment, in either case, but that alleviation from disability can be obtained by co-operation between the user and the designer of the equipment. Such co-operation is, of course, necessary in any problem, not only of lighting but in the whole range of knowledge from engineering to medicine and even literature. It appears, however, to be more necessary to emphasise the importance of this co-operation in the case of lighting equipment than in the case of mechanical devices. For example, no motorist would expect his car to run without oil, the majority will have the engine decarbonised when necessary, but how many ever bother to see if their lamps are in really good condition?

The most fruitful lines of development will be discussed for both problems, and it is in this part of the discussion that the difference between the dazzle and fog problems will become evident. In the case of the

dazzle the discussion will lead to an examination of existing methods, which may be classed as "beam control," and of the theoretical proposal which has attracted so much attention, namely, the use of polarised light. In both cases the results of the careful analysis of what actually occurs will be evident. Finally, the solution of the dual carriageway will be touched upon. It will be shown that the dual carriageway may give the complete solution, but unless it is really effective, incomplete application will prove to be more dangerous than the ordinary open road, due to the failure to show up objects by silhouette, a very important factor in vision under dazzle conditions. The relation with street lighting will only be mentioned, as it is beyond the scope of this paper. The importance of the relationship cannot be underestimated, and must shortly receive the earnest attention of designers in both fields of illuminating engineering.

In dealing with the fog-lamp, use will be made of the latest available meteorological developments in the theory of seeing, and the effect of coloured light will be examined. The present method of attack will be described and also its logical extension. Finally, two possible aids to vision will be mentioned.

The aim throughout is to provide a background of fundamental fact and theory on which any technical development must be based if it is to be successful. The mode of action of the human eye itself is probably the least appreciated factor in this background, and the proportion of attention given to visual theory probably errs on the small side rather than on excess. It must be stressed that this aspect of the problem is capable of scientific treatment as is the engineering one. The complexities of the theory of vision are evident, but must lead to an attitude calling for the judgment of the expert rather than the more common attitude which assumes that the introspective examination of the layman is the surest basis for design.

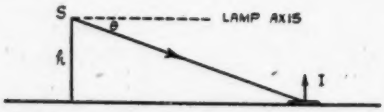


Fig. 1. Illumination of horizontal road surface.
S, Source of Light.
I, Illumination on horizontal surface.
h, Mounting height.

PART I.

General Theory of Headlamp Beam Design.

It is usual to discuss the road brightness achieved by a particular headlamp beam in terms of the illumination produced on a horizontal plane in the surface of the road and the reflection factor of the road. These conditions are illustrated in Fig. 1, in which the illumination, I, on surface element at an angle θ, from the source of light is being examined. Treatment on this basis is very unreal and makes the presentation of any fundamental theory extremely difficult for the following reasons:—

(a) Roads are not horizontal surfaces of extreme flatness.

(b) Experiment indicates that the apparent value of the reflection factor depends upon the angle of incidence, increasing to very high values at grazing incidence. (1)

(c) The lamp and road are not, in practice, fixed relative to each other.

(d) The driver is not concerned with the horizontal illumination, but with the apparent brightness of the road surface as seen from very near the lamp.

In order to develop a general theory on which the design of headlamp beams can be based, it is necessary to treat the illumination problem in an entirely different way.

The beam candle-power must be so distributed that the appearance of the road and its boundaries is nearly uniformly bright, when viewed from a position near the lamp. As has been stated, the road surface is not one of extreme flatness, and this applies more particularly to the road margin, which may be a hedge or grass bank.

Suppose, therefore, the road or road boundary is made up of a large number of small planes all lying normal to the incident light and projecting from the surface by which we normally designate the road or its margin. This

situation is depicted in Figure 2, where the lamp and observer are supposed to be at S, h denotes the vertical distance between the lamp and the road, θ is measured from the lamp axis and serves to define the relation between the candle-power and its direction of emission, and ϕ is the angle between the lamp axis and the surface of the road in the plane under consideration. The surface, H, is supposed to be illuminated so that any

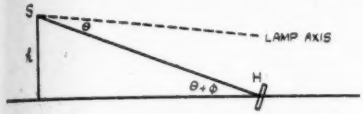


Fig. 2. Brightness of surface elements along the road.

S, Source of light. H, Brightness of surface normal to light.

h, Mounting height. ϕ, Angular error of mounting.

θ, Angle defining candle-power from source.

such surface along the road will present a substantially uniform brightness to the observer.

To find the relation between the candle-power C_θ and the angle, θ, it is necessary to make two further assumptions, namely (a) the reflection factor of the imaginary surface is constant and (b) the changes in ϕ are generally small compared with the values of θ and are rhythmical.

The section depicted in Fig. 2 may be either vertical, horizontal, or oblique, but in practice it is only necessary to consider a vertical section (h = lamp mounting height) and a horizontal section (h = semi-width of road) and assume an elliptical beam cross-section.

TABLE OF SYMBOLS.

C = Candle-power given by headlamp.
I = Illumination.
h = Perpendicular distance between lamp and road surface or road margin.
θ = Angle from lamp axis.
$\triangle\theta$ = Small range of values of θ.
ϕ = Angle between lamp axis and road direction.
$\triangle\phi$ = Small range of values of ϕ.
$n = \frac{\triangle\theta}{\triangle\phi}$ Ratio of range of values of θ to corresponding range of values of ϕ.
A = Constant of Integration = $I_{\theta_1} h^2$.
D = Distance between lamp and road margin.
W = Width of road.

The illumination, I, at H, can be written:—

$$I = \frac{C_\theta}{h^2} \sin^2 \overline{\theta \pm \phi} \ldots,\ldots\ldots(1)$$

which on differentiating with respect to θ and ϕ gives:—

$$\left(\frac{dI}{d\theta}\right)_\phi = \frac{2C_\theta}{h^2} \sin \overline{\theta \pm \phi} \cos \overline{\theta \pm \phi} + \frac{\sin^2 \overline{\theta \pm \phi}}{h^2} \frac{dC_\theta}{d\theta}$$

$$\left(\frac{dI}{d\phi}\right)_\theta = \frac{2C_\theta}{h^2} \sin \overline{\theta \pm \phi} \cos \overline{\theta \pm \phi}$$

$\left(\frac{dI}{d\phi}\right)_\theta$ will be a measurement of the change in illumination due to errors in setting, whilst $\left(\frac{dI}{d\theta}\right)_\phi$ will indicate the changes in illumination along the road surface. Since there seems no reason to suppose that either spatial or temporal changes should have preference, the relation between the two differentials should be of the form,

$$\int_\circ^{\theta\ \max} \left(\frac{dI}{d\theta}\right)_\phi d\theta = \int_\circ^{\phi\ \max} \left(\frac{dI}{d\phi}\right)_\theta d\phi \ldots\ldots(2)$$

which in the simplest case reduces to

$$\left(\frac{dI}{d\theta}\right)_\phi \triangle\theta = \left(\frac{dI}{d\phi}\right)_\theta \triangle\phi \ldots\ldots\ldots(3)$$

$$\text{or} \quad n\left(\frac{dI}{d\theta}\right)_\phi = \left(\frac{dI}{d\phi}\right)_\theta$$

when

$$n = \frac{\triangle\theta}{\triangle\phi}$$

Substituting the values of the differentials and reducing this gives,

$$\frac{dC_\theta}{C_\theta} = \frac{2(1-n)}{n} \cot \overline{\theta \pm \phi}\, d\theta \ldots\ldots\ldots(4)$$

In the practical application of this equation the values of ϕ can be replaced by a constant ϕ_1, which is the

average value of the displacement each side of the mean. Suppose θ is much smaller than ϕ_1, then clearly the right-hand side of the above equation is very nearly constant with respect to θ, thus

$$C_\theta = \text{constant (for } \phi_1 > \theta > 0)$$

However, when θ is much larger than ϕ_1,

$$C_\theta = A \sin\left(\frac{2(1-n)}{n}\right) \overline{\theta \pm \phi}$$

when A is a constant of integration.

When the average value of ϕ is taken in any real case it is clear that,

$$\Sigma\phi = 0$$

Further, when the lamp is mounted rigidly so that $\phi_1 = 0$ and n is large

$$C_{\theta_1} = A \sin^2 \theta$$

or

$$A = C_{\theta_1} \sin^2 \theta_1 = I_{\theta_1} h^2$$

giving two expressions for the constant of integration.

Thus the general solution for the relation between C_θ and θ is, to a first approximation,

$$\left.\begin{aligned} C_\theta &= I_{\theta_1} h^2 \sin^{-2} \theta_1 = \text{constant} \\ &\qquad \left(\text{for } \phi_1 \geqq \theta \geqq 0\right) \\ C_\theta &= I_{\theta_1} h^2 \sin^{\frac{2(1-n)}{n}} \theta \\ &\qquad \left(\text{for } \theta_{max} \geqq \theta \geqq \phi_1\right) \\ \theta_1 &= \phi_1 \end{aligned}\right\} \quad (5)$$

These equations give the relation between the candle-power and the angle of emission in order to create the most even average brightness on elements normal to the incident light projecting from a plane lying parallel to the axis of the mean position of the lamp, which is itself subject to rhythmic movements. They apply only to the special case of the observer being very near to the source. In order to apply the equations to a real situation values must be chosen for the constants. Clearly the value of h will be determined by the scale of the equipment, whilst I_{θ_1} will be chosen after consideration has been given to the brightness required, and the flux available. The value of ϕ_1, which will best serve, is not always immediately obvious, nor is the value of n. This is particularly so when small values of ϕ_1 are required and the reason lies in the fact that the simple form of the expression (2), which is used instead of expression (3), is in reality an oversimplification of the situation. However, the use of a more correct relation would lead to an unmanageable differential equation in place of equation (4), and the course adopted must depend for its justification upon the practical use of the results.

The Open Road Beam.

The illumination required for driving on a main highway in the absence of other drivers is relatively simply specified. The brightness over the whole of the field of view should be nearly constant, and the flux in the beam should be such that any obstacle in the path of the vehicle is shown up as a bright object contrasting with the rest of the field. This result will be inevitable since the object will receive greater illumination than the background. The problem of obtaining even brightness under these conditions can be resolved into two separate divisions, namely the horizontal and vertical beam distributions. The section of the beam, at right angles to the forward direction, will be elliptical and the intensity in oblique directions will be defined by the distributions along the major and minor axes.

Horizontal Distribution. — When travelling along a main road a vehicle may be assumed to follow the road very closely, and the infrequent occurrence of turnings will render them relatively unimportant. The accuracy with which the vehicle axis follows the road direction will justify a large value of n. On the other hand the changes in road direction will not at the same time permit the use of a very small value of ϕ.

The value of $C_{\theta=0}$ is limited mainly by the purely practical consideration of the available flux, but also by the flux density, which it is permissible to have in a beam without undue

scattering of light into the driver's eyes.

From these considerations, a value of

$\theta_1 = \phi_1 = 2°$ is chosen

together with

$n = \infty$

$h = 10$ ft. (h denoting the semi width of the road).

$I_{\theta_1} = 1$-ft.-candle

Thus, substituting these values in the general equations,

$C_\theta = 82{,}000$ c.p. (for $2° > \theta > 0$)

$C_\theta = 100 \sin^{-2}\theta$ c.p. (for $\theta > 2°$)

These results, which are perfectly logical in that they state that the illumination along the road margins should be constant, are plotted in Fig. 3 and compared with (a) an experimental beam designed as a result of a particular solution of the above theory and later introduced into the standard Lucas range of lamps, and (b) the provisional American Standard Driving beam.

The agreement between the theory and the experimental data indicates that the design of that lamp achieved its object, and that the results are practicable. However, the agreement between the theory and the proposed American beam seems to indicate an agreement as to the general form of the lamp beam.

Vertical Distribution.—As in the case of the horizontal distribution, it is possible to choose tentative values of the parameters, and these have to be selected so that the results will fit in with those for the horizontal distribution,

$\theta_1 = \phi_1 = 1°$

$n = 4$

$C_{\theta_1} = 82{,}200$ c.p.

Thus $I_{\theta_1} h^2 = 189 \cdot 8$ (h denoting the mounting height of the lamp).

and $C_\theta = 189 \cdot 8 \sin^{-1.5}\theta$ (for $\theta > 1°$)

In Fig. 4 this solution is compared with the vertical distribution of the

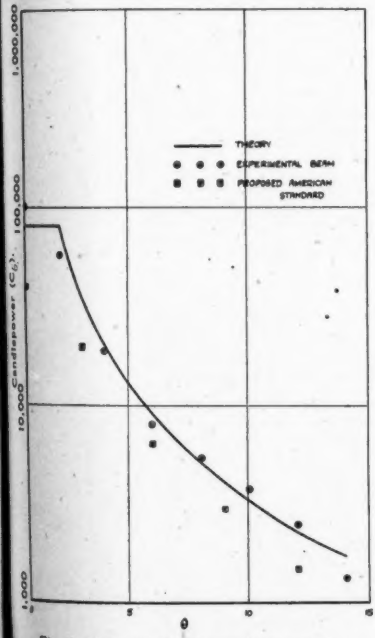


Fig. 3. Main driving beam (horizontal distribution).

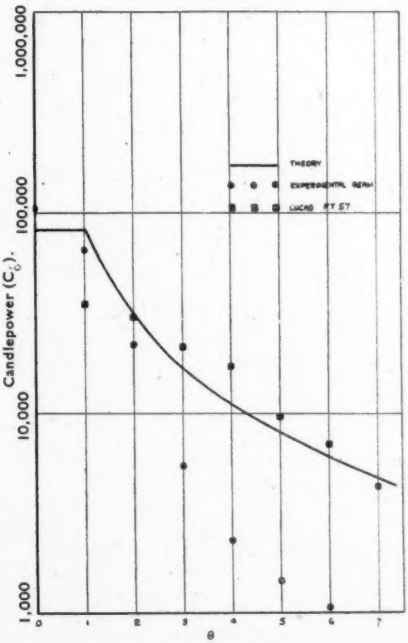


Fig. 4. The vertical distribution.

experimental beam and also with the vertical distribution of a Lucas F.T.57 fog lamp. It is evident that the distribution given by the experimental lamp is too narrow, but that the F.T.57 agrees substantially with the theory.

The selection of a value for n is carried out in the following manner. Suppose one imagines the field of view of the driver to be limited to the range $\theta = 0$ deg. to $\theta = 12$ deg. in the vertical sense below the horizontal, and suppose the maximum value of ϕ is 3 deg., then

$$\frac{\triangle\theta}{\triangle\phi} = n = 4$$

and

$$\frac{2(1-n)}{n} = -1 \cdot 5$$

In Fig. 5 are shown values of the expression

$$y = A \sin^{\frac{2(1-n)}{n}} \theta$$

plotted so that $y = 10{,}000$ when $\theta = 1°$

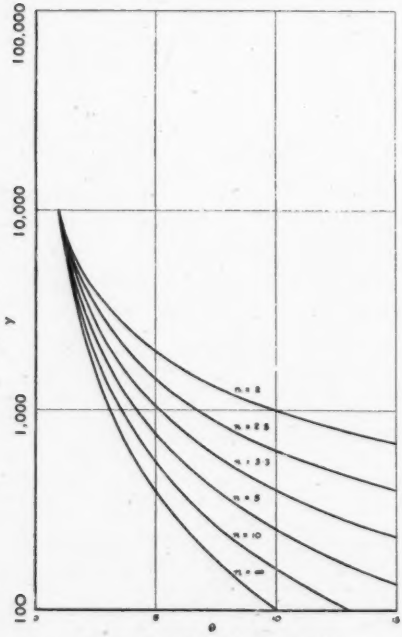


Fig. 5. Showing the effect of the Parameter "*n*."

from which it is evident that the value of n in any case requiring a large value of n will not be very critical.

The Horizontal Plane Diagram.

Since it is evident that the main concern in the design of a headlamp beam is to give a constant illumination over the surface of the field of view, it is convenient to present experimental results in such a form as to show to what extent this has been achieved.

So before discussing the significance of the width of the beam it is worth while examining in detail the form of diagram used in Fig. 6, which shows the same results as Fig. 3 plotted in a different form. In general, the illuminating engineer uses either an iso-candle diagram or a polar diagram in which the candle-power is plotted radially. The iso-candle diagram must always remain the fundamental basis from which to work, because it enables a large amount of data to be tabulated in an orderly manner, but the polar diagram, in that it selects one plane for more detailed examination, is far more convenient for the presentation of experimental results. The very large changes in candle-power with angle make the conventional polar diagram far too cumbersome for the presentation of headlamp beam data. For this reason it was decided to use a new form of polar diagram, and since the significant attribute is finally the brightness, it was decided to plot curves of constant illumination.

Moreover, since it is well known that the eye responds very nearly to equal percentage changes in illumination, it was decided to use a scale so that a given change represented an equal percentage change anywhere along the scale. Thus the results are plotted in terms of the square root of the candle-power (i.e., the distance to give 1 foot-candle) on a logarithmic scale.

This type of diagram has the particular advantage that it gives a very good picture of the beam to the designer and enables him to gauge its performance in practical test with some confidence. If the ideal curve for the horizontal distribution is continued beyond the range discussed

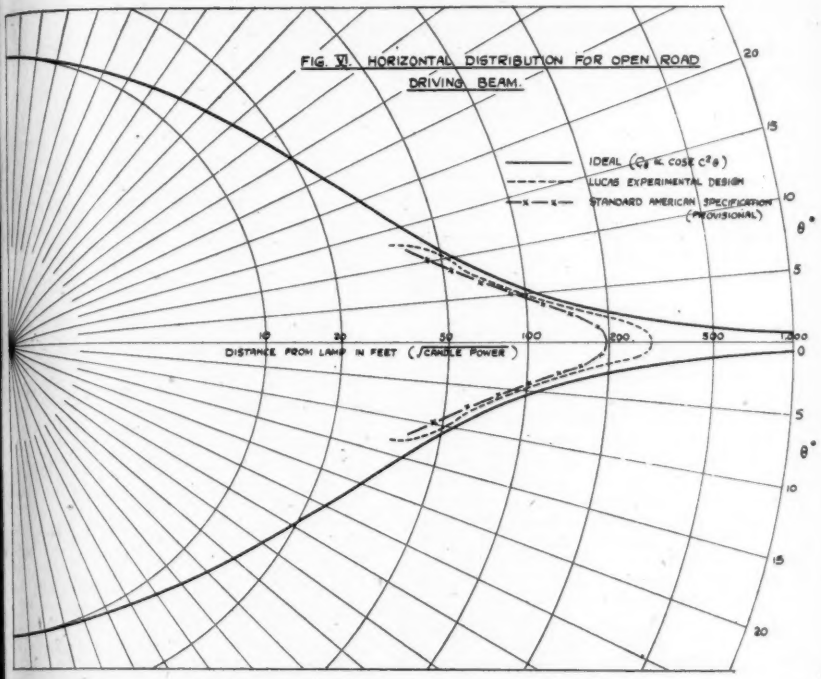


Fig. 6. Horizontal distribution for open road driving beam.

above, it can be seen that a projection of a 20-ft. wide road on a logarithmic scale extending from 1 ft. to 1,000 ft. is obtained. The expression

$$C_\theta = I_{\theta_1} h^2 \sin^{-2}\theta.$$

can in fact be replaced by

$$D = \frac{W}{2} \operatorname{cosec} \theta.$$

where D is the distance of the point on the side of the road from the headlamp, and W is the width of the road. If an experimental curve is plotted and compared with the road contour it is easy for the designer to assess the significance of the departures from uniformity of the illumination that would be given at the edge of the road. Thus not only does this form of polar curve provide a ready means of recording results, but also a pictorial means of analysing those results.

Practical Limitations of the Theory

In both the theoretical expression for the relation between candle-power and angle and in the practical results no indication has been given as to the limits of the value of θ to which the theory may be expected to apply. The most important factors determining this limit in the case of the horizontal distribution are (a) the luminous flux available, and (b) the angular width of visual field required. In the experimental beam shown in Figs. 3 and 5 the candle-power falls below the ideal for values of θ greater than $\theta = 13$ deg., thus giving a horizontal width of the field of view of 26 deg., which has in practice proved satisfactory for the main driving beam. In effect, the driver's attention is directed to the road beyond 40 ft. from the vehicle, which is obviously desirable for a fast-moving vehicle. In practice the flux available, 1,200 lumens from

two 12-volt 36-watt bulbs, is adequate to provide this horizontal distribution, even though the vertical distribution may be somewhat below the ideal.

The lower limit of the value of θ to which the general expression may be applied depends upon the value of ϕ, and although this is controlled by the possible deviations of the path of the vehicle and, of course, by the expected curves in the road, there is a further factor which deserves attention. If a value of ϕ considerably below $\phi = 2$ deg. were selected, and the remaining constants unaltered, then the value of C_{θ_1} would become very large, with the result that there would be a very high flux density in the beam for some distance in front of the lamp. In slightly misty weather such a high flux density would cause a considerable distraction owing to the light scattered by the small particles in the air towards the driver's eyes. It appears that when the candle-power exceeds about 100,000 c.p. this back scatter may become annoying, although the general loss of visibility is not otherwise noticed.

In the vertical sense, below the horizontal, the limits are much more clearly defined. In most modern cars the field of view of the driver is limited to beyond 15 ft. from the vehicle, thus the illumination produced by light given out at more than 10 deg. below the horizontal is very unlikely to be appreciated, whilst $\theta_{max} =$ 7 deg. or 8 deg. would be a reasonable working limit.

The value of ϕ will again determine the lower limit for θ, and very small values should not be selected for the same reasons as in the case of the horizontal distribution.

General Recommendations

It is evident that, in the case of the open road driving beam, purely theoretical considerations will lead to a beam specification that is essentially practicable, and, moreover, experiment appears to indicate limiting conditions which make it possible to specify a beam distribution, for a main driving beam, which, if not ideal, at least can be called a "preferred" distribution.

Such a specification is illustrated in Figs. 7, 8, and 9. Fig. 7 shows the curves plotted as a simple relation between the candle-power and the angle, and Fig. 8 shows the same values replotted on the horizontal plane diagram described above. Lastly, Fig. 9 shows the same data plotted for comparison with the provisional American "Upper beam" specification which is given in Fig. 10.

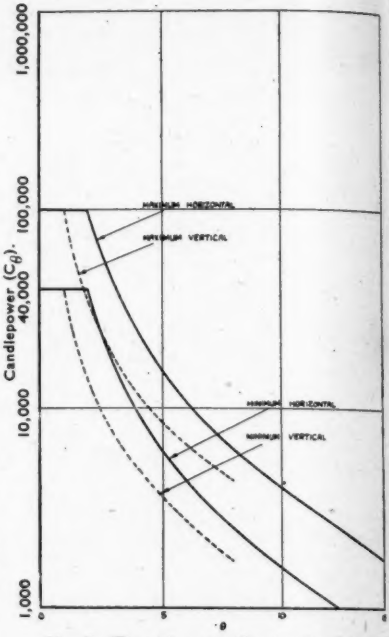


Fig. 7. Tentative specification for main driving beam.

In interpreting the above specification it must, of course, be understood that the discontinuities occurring at the points $\phi = \theta$ are not intended for reproduction in a real beam, but occur in consequence of the method of solving differential equation defining the beam requirements. It will be remembered that two cases gave simple solutions, namely (a) $\theta \ll \phi$ and (b) $\theta \gg \phi$, thus the use of the solutions in the region of $\theta = \phi$ is not strictly justified. It is for this reason that the curves shown in Fig. 8 have been smoothed in the

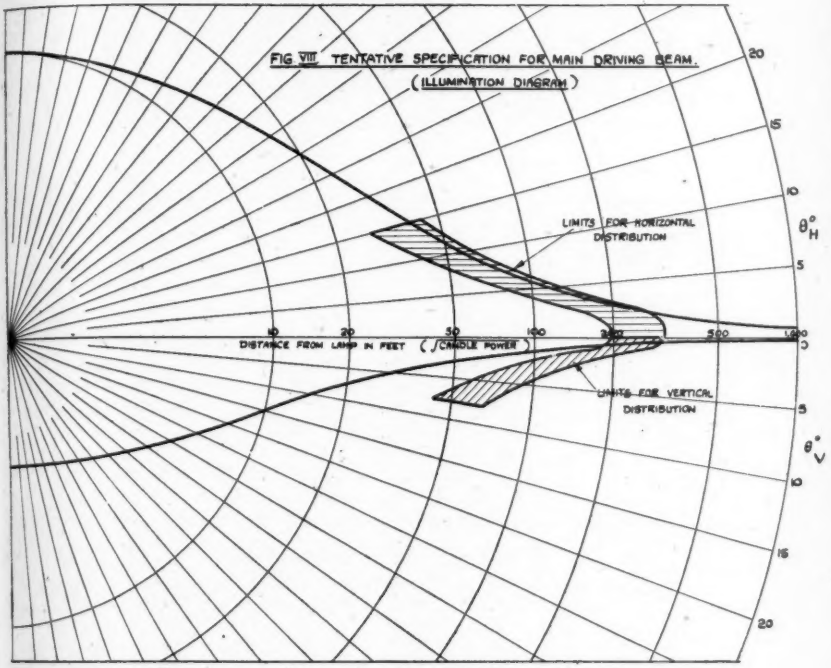


Fig. 8. Tentative specification for main driving beam (illumination diagram).

region of $\theta = \phi$, and thus present a more nearly correct solution.

The City Beam

Before going on to the subject of the design of a passing beam to alleviate dazzle, it is worth while considering the horizontal distribution for a lamp beam intended only for city driving. The final design of a passing beam must to some extent be based on such a beam, but it is convenient to consider the problem of the horizontal distribution in isolation from that of dazzle prevention.

The essential difference between the horizontal distribution required for the city driving beam from that required for the open road beam will be in the value of the parameter, ϕ_{max}, the greatest permissible maladjustment. This will be primarily due to the fact that at corners the vehicle may be at quite a large angle to the direction of the road, but in practice the value of ϕ can best be assessed by considering the greatest distance along the road that one is likely to be able to see and therefore need light. It is evident that if critical vision is possible for 100 ft. in front of a vehicle, safe driving will be assured in a city; moreover, as will be seen later, it is not practicable to provide illumination further from the vehicle than this in the case of a passing beam.

Suppose the ideal case of a 20-ft. wide road, with the illumination unit mounted in the centre, is considered, as in the case illustrated in the explanation of the horizontal plane illumination diagram. In Fig. 11 it is clear that if the beam is to be limited to 100 ft., then a value of $\phi = 5.75$ deg. can be used, and if this is combined with the same order of illumination as required by the open road driving beam, the resulting beam distribution will be approximately as

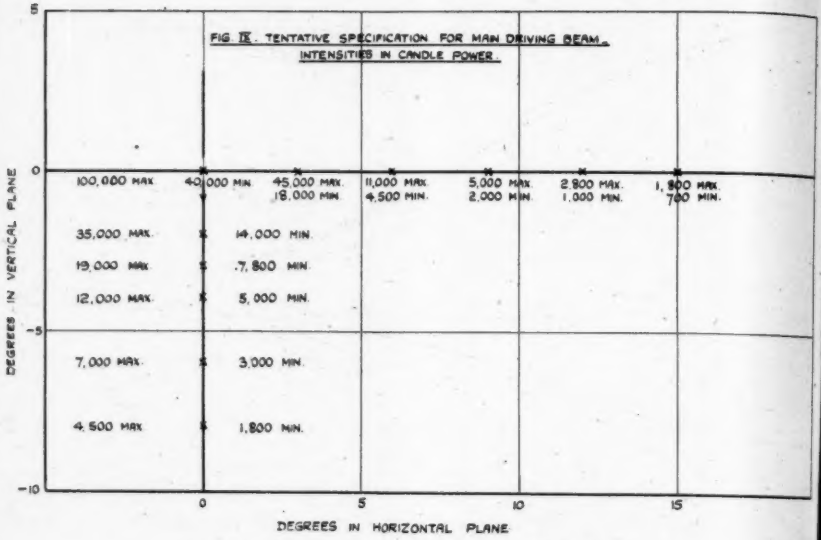


Fig. 9. Tentative specification for main driving beam.

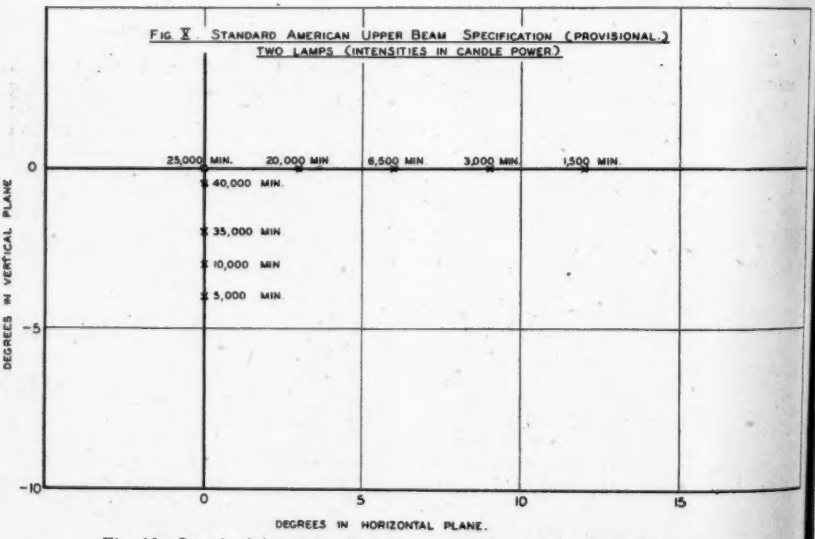


Fig. 10. Standard American upper beam specification (provisional) for lamps.

indicated in the cross-hatched area in the diagram.

In Fig. 11 the value of θ_{max} used is 30 deg., which would mean that an even illumination down the sides of the road would be provided from 20 ft. to 100 ft. Beyond 30 deg. the illumination would fall, but not as rapidly as shown in the figure, which is concerned with a purely idealised distribution. An experimental beam made to the above specification is also shown in Fig. 11, and it can be seen that in a practical case, whilst the general form is as required by the theory, the corners are rounded.

The vertical distribution below the axis should not need treatment any different from that given for the open road driving beam.

PART II.

The Passing Beam.

In the design of the beam for use on the open road and also in the choice of the City beam no account has been taken of the effect such beams might have on other road users. It has, in fact, been assumed that no other vehicle was present, and although this state of affairs will occur over long stretches of main roads in the country, it is becoming increasingly rare in urban areas and in the vicinity of large towns. It is necessary, therefore, to consider the form of lighting which should be used when (a) two vehicles meet on a main highway and (b) for use in urban areas where the density of traffic is high and two streams of traffic may be proceeding in opposite directions. It is possible that these two cases may lead to the same solution, but it seems advisable to bear in mind that there are very real differences between them.

Discomfort and Disability.

If two vehicles, both equipped with main driving beams, meet, and if the drivers make no alteration to their

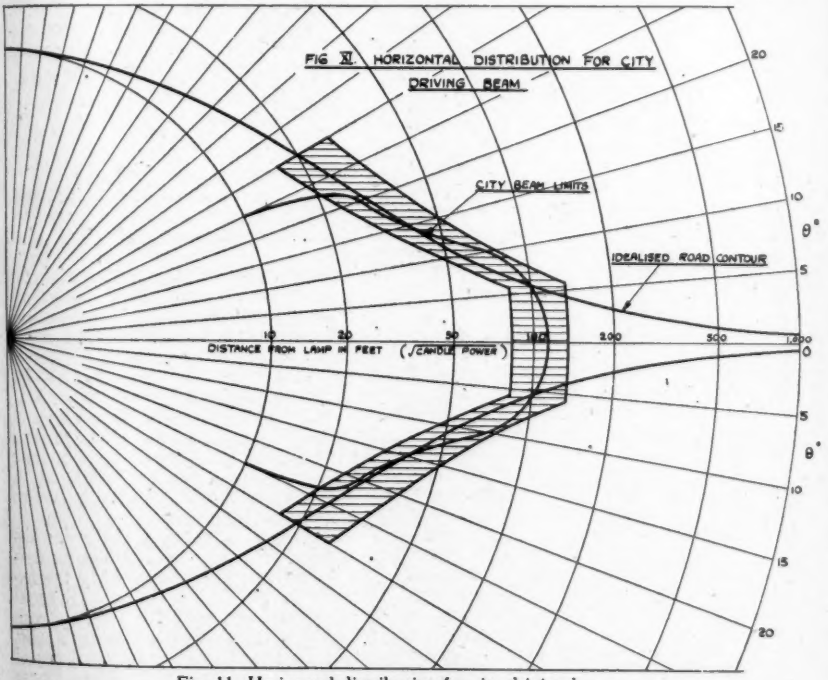


Fig. 11. Horizontal distribution for city driving beam.

beams, then both will suffer from dazzle which will be manifest in two ways:—

(a) marked discomfort experienced by drivers,

(b) serious reduction in the distance at which the drivers can perceive obstacles in their paths.

These two effects of dazzle, the discomfort and the disability, are quite separate and distinct, and although it is evident that anybody who suffers continual discomfort will in consequence experience disability, the essential difference between the two different effects of dazzle must not be forgotten.

The effect of dazzle that can be assessed by introspective examination is clearly only discomfort. Thus the opinions and experiences of even the most observant motorist are only of consequence in assessing the disability caused by dazzle in so far as the effects of disability and discomfort follow strictly the same course. Clearly it is most important to reduce the disability effects of dazzle to a minimum, and only when this has been achieved can the question of discomfort receive attention. It is, of course, evident that a light which causes discomfort will also cause disability, but, under a given set of circumstances the choice of lighting to give the greatest visibility may not be that one which gives the greatest comfort, and if the discomfort is not very large, visibility and safety should not be sacrificed in the interests of comfort.

Disability Glare.

The effect of a glaring light source in the field of view on the ability of the eye to detect small differences in contrast has been studied exhaustively, notably by Stiles ([2]). It has been shown that the effect of the glare source depends upon (a) the illumination caused by it at the eye of the observer, and (b) the angular separation between the glare source and the object under observation. The reduction in the visibility under any given set of circumstances can be expressed quantitatively in terms of an equivalent veiling brightness, which is imagined to cover the whole field of view and which would cause the same reduction in visibility as caused by the glare source. The equivalent veiling brightness, B, is related to the field brightness, Bo, the illumination at the eye due to the glare source, I, and the angle, θ, between the glare source and the object of attention by the expression:—

$$B = B_0 + \frac{10I}{\theta^2}$$

The above expression is not in the most convenient form for application to the ease of glare from an automobile headlamp. The geometry of the situation lends itself to a far more simple expression as is evident from Fig. 12.

If the candle-power, C, from the dazzling lamp is assumed to be constant with respect to θ, for large values of D, then the above expression can be rewritten as

$$B = B_0 + \frac{10C}{d^2}$$

from which it can be seen that the equivalent veiling brightness and thus the effect of the dazzle depends only upon the candle-power towards the driver's eyes, since the

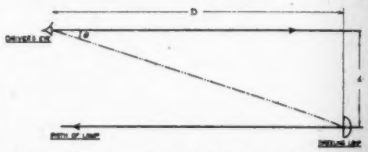


Fig. 12. Geometry of the dazzle problem.

lateral separation, d, remains constant as the vehicles approach. This fact has been used by V. J. Roper and E. A. Howard ([3]), who have determined the visibility distance for a given candle-power towards the eye as a percentage of the value with no dazzle. Their data is given in Fig. 13, from which it is evident that the results may be extrapolated for values of the candle-power above 10,000 c.p., since the relation shown is substantially linear.

In order to appreciate fully the significance of Roper and Howard's data it is worth while considering the following hypothetical case. Suppose there are two vehicles facing each other at a considerable distance apart and suppose that each has a lamp of the same candle-power. If the power of the lamps is very low indeed,

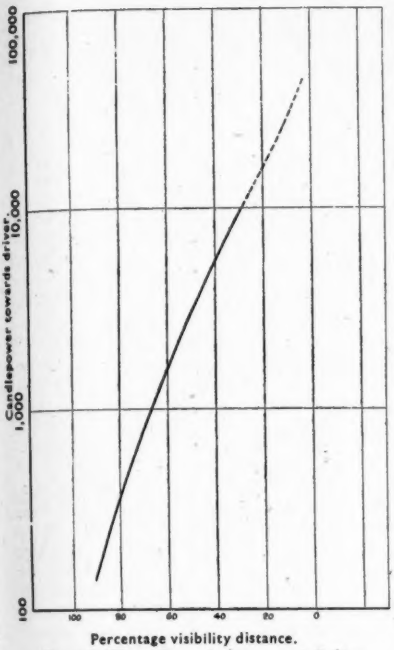


Fig. 13. The effect of glare on visibility distance.

clearly neither driver will be able to see, because he has no light. On the other hand, if each lamp is extremely powerful (say 100,000,000 c.p.), neither driver can see because each is dazzled by the lamp on the other vehicle. Between these two extremes there will be a certain range of values of the lamp candle-power for which each driver will have a substantial range of visibility.

In their paper Roper and Howard give data relating the visibility distance for a pedestrian in dark clothing with the candle-power of the lamp. Their data is extensive, but approximately it may be said that the visibility distance is the distance at which the illumination produced by the lamp is 1 ft.c. Although it must be realised that such an approximation leaves out of account many significant factors, for rough practical calculations it is convenient to be able to take the visibility distance as the square root of the candle-power. These two sets of data can conveniently be combined so that we can find the relationship between the visibility distance and the lamp candle-power when the driver has to face a lamp of equal candle-power shining towards his eyes. These results are given in Fig. 14 and show that the visibility distance increases slowly to a flat maximum and then falls as the candle-power is further increased.

Whilst the results given in Fig. 14 must not be taken to be numerically accurate they do indicate the general nature of the results to be expected in practice. The results can be used to bring out the difference between the discomfort and disability due to glare. Suppose we consider three lamps having the following beam candle-powers:—

(a) 920 c.p.
(b) 8,000 c.p.
(c) 24,000 c.p.

If these three lamps are to be assessed according to the amount of discomfort they cause, which is the only method the vehicle driver can use, then the results will always place them in the following order of increasing discomfort:—

a, b, c.

Reference to Fig. 14, however, shows that if placed in the order of increasing disability the results should read:—

b, a, and c.

The designer must choose a specific lamp for his purpose, and it is clear that if he has only a and c from which to choose the choice must always favour 'a' since it results in greater comfort for the same degree of ability. The choice between 'a' and 'b' is not so easy to make unless a great deal more is known about the conditions of use.

If, for example, the lamps are to be used for a relatively short time, and both drivers are fresh and unlikely to suffer fatigue during the drive, then the lamp 'b' would be indicated definitely. On the other hand, if the lamps are to be used for a long time, as where two streams of traffic pass, and both drivers will suffer from very considerable fatigue, then the lamp 'a' may be preferred. It is, in fact, necessary to compromise between the short period test depending only upon

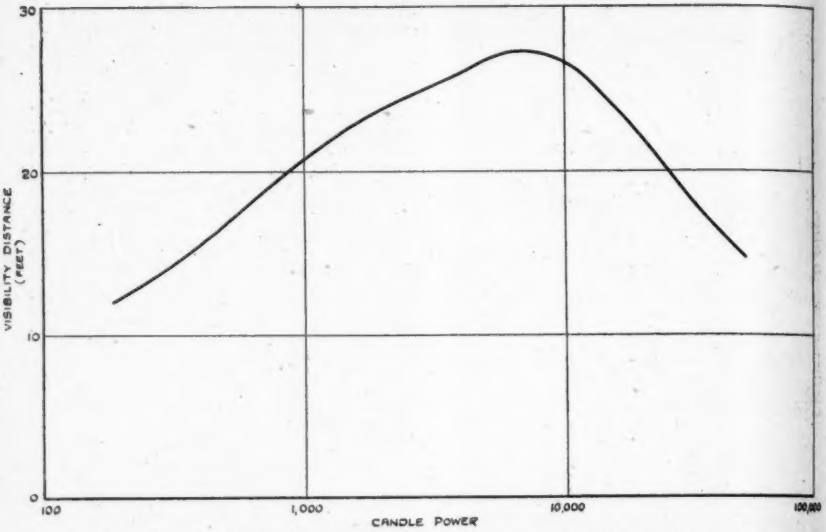


Fig. 14. Showing the change in visibility distance when a driver faces headlamps of the same candlepower as his own.

visibility and the long time use in which successive experiences of discomfort may accumulate to cause fatigue.

Vision by Silhouette under Glare Conditions.

Before attempting to discuss the most suitable form of beam design for use under glare conditions, reference will be made to some further work carried out at the Nela Park Laboratories of the General Electric, and reported by H. H. Magdsick at the International Commission of Illumination in 1939 (4). In considering the visibility distance under glare conditions, it has been assumed that objects are seen by the light of the drivers' own headlamps, an assumption which, while largely true, is not so far for the whole time during the passing two vehicles. Fig. 15 is adapted from Magdsick's paper, and it can be seen that when the two vehicles are approaching from a great distance (left-hand side of the diagram), the visibility distance is about 150 ft., and the effect of dazzle on the ease of seeing the dummy pedestrian in dark clothing is negligible. As the two vehicles approach, it can be seen that the visi-

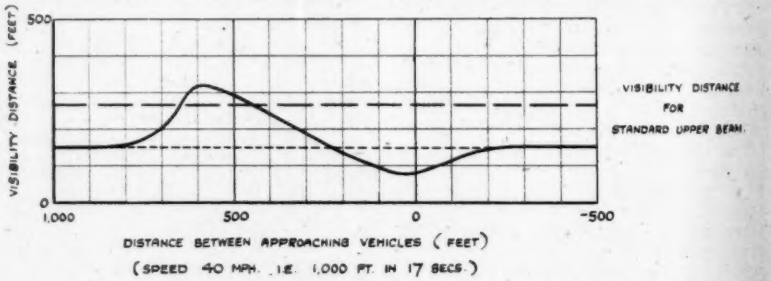


Fig. 15. Changes in visibility distance using American "lower beam."

bility distance increases very considerably, finally reaching a value of 330 ft. This increase in visibility distance is due entirely to the fact that the pedestrian is shown up in silhouette against the bright patch on the road caused by the lamps of the opposing car. As the two vehicles approach nearer, the visibility distance falls to a minimum of about 80 ft., when the pedestrian is just behind the approaching car. Finally, the visibility distance rises to its former value of 150 ft. as the drivers recover from the dazzle.

Whilst the actual values of the visibility distances quoted refer to a specially designed American passing beam, this sequence of events is fundamental, and will always occur when two vehicles meet. The implications of this analysis are extremely important for a clear understanding of the problem of dazzle prevention. For example, it is quite evident that the ill effect of the considerable reduction in the visibility distance which occurs as the opposing car approaches and passes the dummy is minimised by the increase in visibility distance preceding it. The increased range due to the silhouette vision will, in fact, about equal that given by the open road beam; moreover, this will occur at a time when the driver is suffering from discomfort glare. Under these circumstances, it is evident that the introspective judgment of the driver may be misleading, and result in an overestimate of the disability effect.

Principal Aspects of Glare Problem.

The problem of dazzle, at least in its purely technical aspects, can now be briefly surveyed. When two vehicles meet at night, both drivers will suffer from dazzle due to the opposing car's lamps. The distance at which a driver can see by the light of his own lamps is determined by the candle-power in the direction of the object to be seen, but is reduced by the candle-power from the opposing car's lamps shining into his eyes. The effects of this dazzle are two-fold: (a) both drivers experience discomfort, and (b) both drivers suffer from a considerably reduced range of visibility. Since these two effects follow somewhat different laws, the discomfort may be accentuated and the effects of disability will be insidious.

When the two vehicles are a considerable distance apart, objects between the two vehicles may be shown up in silhouette to one driver by the patch on the road lit by the lamps of the opposing vehicle. This effect causes a very considerable increase in the visibility distance under glare conditions, and is probably the reason why the dazzle problem is not far more serious than it is already.

The above analysis of the problem shows that there are three main points which must be taken into account in any solution of the dazzle problem:—

(a) The candle-power illuminating objects in the path of the vehicle should be as high as practicable.

(b) The candle-power above the horizontal plane and in the direction of the eyes of the opposing driver should be as low as possible.

(c) The beam distribution of the lamp below the horizontal plane should be such as to produce a uniform brightness over the road surface to enhance the visibility of objects by silhouette.

Although the above factors are the three fundamental ones controlling the design of lamps for use under dazzle conditions, they are not sufficient alone to permit the design of a satisfactory passing beam. The following factors arise from the peculiarities of the situation and are of equal importance:—

(d) Since the vehicle is in motion the lamp beam must be designed so that when the car is pitching and tossing a normal amount, the candle-power towards the opposing driver's eyes is not excessive. It may be taken that a car may frequently pitch as much as 2 deg. up and down. In consequence the maximum candle-power must lie about 2 deg. below the horizontal.

(e) It is evident that a very sharp fall in candle-power is desirable in the region of the horizontal. Experience, however, shows that if the cut-off is too sharp the

resulting seeing conditions are poor because the movement of the cut-off in the field of view provides a continual source of distraction. For this reason the fall in candle-power must be graded so as to avoid causing undesirable contrasts.

Review of Proposed Solutions of the Dazzle Problem.

Having reviewed the phenomena associated with dazzle and stated in general terms the conditions to be fulfilled by a passing beam, it is now possible to discuss how these principles can best be applied in practice. In considering the relative merits of each alternative method it is necessary to bear in mind the following points:—

(a) Is the solution applicable to two streams of traffic passing as well as to two isolated vehicles? In the former case it is obvious that the effects of discomfort will be accumulative and thus more important than in the latter case.

(b) Must a driver perform some action to relieve another driver of inconvenience? If so, is it possible to demonstrate that the driver's own interests are also served?

(c) Does the proposed system involve any unnecessary, or apparently unnecessary, sacrifice of visibility? If so, what precautions are to be taken to ensure that the equipment is not misused.

It will be obvious from the above that the criteria for examining the efficacy of a method of dazzle prevention are very largely concerned with how the motorist will use the system and not entirely limited to the strictly technical problems of illuminating engineering. The motorist must in fact be given a solution which he can see gives him advantage and which he can understand. The following possible courses are open for the solution of the glare problem:—

I. The use of permanently non-dazzling (or partially non-dazzling) headlamps.

II. The use of special lamps for the passing beam the distribution of which should be controlled either by custom or legislation.

III. All headlamps should be fitted with polarising screens and all drivers carry some form of analyser.

IV.—Dual carriage-ways should be used.

V. All traffic routes should have street-lighting.

I. The Non-dazzling Lamp.—To attempt to prescribe one lamp for use on all occasions may be looked upon as the most elementary approach to the subject of dazzle prevention. It is often supported strongly by the layman, and generally because of his failure to understand the nature of the problem of dazzle prevention. In addition, a compromise is often suggested by which the lamp should be allowed to give a controlled amount of light above the horizontal, so that visibility is eased without causing too much dazzle.

This form of solution has been abandoned by those countries who have tried it, for the following reasons:—

(a) The compromise suggested does not exist in practice, and if there is sufficient light to give a reasonable visibility distance, then, although two lone vehicles may pass in safety, the discomfort caused by a stream of vehicles is intolerable.

(b) In order to get a sufficiently low candle-power towards the opposing driver's eyes the maximum candle-power must be directed below the horizontal. This limits the visibility distance to less than 100 ft. and makes driving at more than 30 m.p.h. dangerous. In consequence, drivers will tilt their lamps upwards to get an increased range of visibility, thus defeating the whole object of the system.

Thus, in terms of the three criteria mentioned above, (a) the system is only suitable for lone vehicles and not for traffic streams; (b) the driver is not required to perform any action to relieve dazzle, a point which, although important, is largely nullified by the fact that both drivers are dazzled; (c) visibility distance is sacrificed, and to a dangerous degree.

II. The use of a Pass-lamp.—In this

solution it is assumed that the drivers of all vehicles have two sets of lamps, one for use on the open road, and the other for use when there is another vehicle approaching. This is, of course, a far more desirable solution technically, since each lamp can be designed for its purpose, and an impossible compromise is not imposed upon the designer. Examining this form of solution under the same three headings as above:—

(a) Since the design of the pass-lamp is independent of the main driving light, it can be chosen to be suitable for the case of two streams of traffic if the situation under which the vehicle is to be used warrants it. It may be necessary for the legislative authority to take into account the peculiarities of its own territory.

(b) The strongest criticisms levelled against this method of dazzle prevention are based on the fact that a driver must do something for another driver's benefit. This is so, and so far no technical solution has been made practicable that does not depend upon the common sense and courtesy of the user. In the case of the permanently non-dazzling lamp, the driver is asked to sacrifice visibility to a point of danger, and rightly he will not, but in this case he is asked to change his lighting when necessary, and even for his own eventual advantage.

(c) This system makes the best job of providing good visibility that can at present be managed. There may be an apparent sacrifice of visibility in that the passing beam must be directed below the horizontal. The best way of ensuring that the pass-lamp is correctly set is to make its setting dependent upon the setting of the main driving beam. Under these circumstances there is an adequate inducement to correct setting, since maladjustment of the passing beam will result in a reduced performance from the main driving beam.

III. Polarised Light.—The use of polarised light offers the ideal solution to the dazzle problem. If this system were in use, all headlamps would have to be fitted with polarising screens, and all drivers would have to carry an analyser either in the form of a visor or of spectacles which would exclude the light from opposing headlamps whilst allowing him to see objects illuminated by his own lamps. The recent introduction of the sheet polarising material, "Polaroid," has made this solution sufficiently nearly practicable to warrant the most careful examination. At this juncture it is not proposed to discuss the subject exhaustively, but merely to state that with the present polarising materials available the universal introduction of polarised lighting is not practicable for the following reasons:—

(a) The loss of light caused by the polariser and analyser amounts to over 80 per cent. of that normally available to the driver. This loss could only be overcome by a radical change in the electrical equipment of vehicles. Development of new materials would circumvent this difficulty.

(b) The analyser and polariser must be set accurately with respect to each other, as incidental movements of the vehicle as it travels will cause annoyance to drivers. In the laboratory the use of a different form of polarised light has been demonstrated and this objection should be overcome.

(c) The toughened glass windscreen commonly used on British cars changes the nature of polarised light and makes the analyser ineffective. The use of the laminated type of safety glass in windscreens would get over this obstacle.

It is evident that the problems to be overcome before polarised light can be used to relieve glare from headlamps are of a technical nature and solutions should be forthcoming. In the meantime it is interesting to analyse the proposal to use polarised light under the same three headings as the previous proposals have been examined:—

(a) It is obvious that the use of polarised light is applicable both to an isolated pair of vehicles and to continuous streams of traffic.

The fact that discomfort is almost entirely eliminated makes the distinction between these two cases very small.

(b) Under no conditions need a driver perform an action to relieve anybody else of dazzle. The system could be applied in such a form that no action on the part of the driver was necessary, but it would be preferable to allow drivers to raise their visors so that they could obtain the benefit of the extra light this would allow. The driver would then have to lower his visor so that he was not dazzled, and it is clear that most drivers would very soon learn to do this quickly.

(c) It is at present the principal objection to the introduction of the use of polarised light that the loss of visibility would be too great for safety. When this objection is overcome it is probable that the light from headlamps will not be appreciably reduced by the fitting of the polariser, so that there should not have to be any extraordinary precautions to see that lamps are not misused. The light losses of the analyser will remain, but these may safely be left to the driver to attend to.

IV. Dual Carriage-ways.—The use of the dual carriage-way has, of course, everything to recommend it from the point of view of the driver, since he is segregated on a private road and cannot be worried by approaching vehicles. Furthermore, the driver is relieved of any responsibility to prevent other road users being dazzled and, finally, there is no loss of visibility entailed in this method of dazzle prevention.

Often dual carriage-ways are built without a sufficiently high barrier between the two roads. This form of construction is liable to introduce very grave hazards due to dazzle, as the low hedge, which does not shield the driver's eyes from approaching lamps, will almost certainly prevent objects being shown up by silhouette. The seriousness of this can best be appreciated by reference to Fig. 15, from which it can be seen that on a normal highway the visibility distance starts to increase when the distance between the approaching vehicles is about 800 ft., and does not fall below the original figure until the vehicles are nearly 200 ft. apart. Thus for 600 ft. there is an enhanced visibility, and this is followed by approximately 400 ft. of reduced visibility. In the absence of the silhouette effect it is clear that there can be no question of any enhanced visibility, and drivers will suffer from a reduced visible range over the whole 1,000 ft. which would seriously increase the danger of accidents.

Whilst the dual carriage-way presents a very attractive means of preventing dazzle, it is not a solution that can be applied universally, as the costs of road building would be prohibitive. The use of this form on construction as a safety measure on trunk roads has, however, much to recommend it. If a main highway is not illuminated by a street lighting installation then any method of dazzle reduction at present practicable will certainly lead to some discomfort when the density of traffic is very heavy. Under such circumstances the dual carriage-way, with an unbroken hedge about 4 ft. high between the two roads, offers a very attractive means of ensuring road safety.

V. Street Lighting.—The dual carriage-way is essentially the rural solution to the dazzle problem on the main highway, whilst street lighting is the urban solution. If really good street lighting is installed the question of using car headlamps need not arise, as drivers can see their route and any potential hazards without any additional assistance. It must, however, be mentioned in parenthesis that very few street lighting installations have been erected which give the motorist both safety and a feeling of well being, because such installations are expensive. In spite of the high costs such installations have been found to be economical by many American cities, and in a few cases the main routes between cities have been lit.

In the opinion of the writer the use of high intensity street lighting should, in this country, be confined to urban areas, where systems of lighting should be superior to those

commonly used before the war. The use of inadequate street lighting systems may cause considerable danger to the motorist, since for the most part the street lighting shows up objects by silhouetting them against a bright ground, whilst headlamps show up objects brighter than their backgrounds. Under these circumstances, it is clear that if the motorist feels that the street lighting is insufficient and turns on his lamps he may actually reduce his ability to see objects in his path, whilst he has given himself a false sense of security, since he can see his route more clearly.

Practical Dazzle Prevention.—From the above discussion it can be seen that although under some circumstances special solutions to the dazzle problem are available in the form of dual carriage-ways and street lighting, the only solution available in most cases is the use of the pass-lamp, which is switched on as an alternative to the main headlamp when two vehicles meet. The pass-lamp can thus be designed to give the form of beam most suited to the conditions occurring when two vehicles meet, and the design can be in accordance with the ideal requirements suggested previously.

In designing a beam distribution for these conditions it must be realised that, except that the candle-power above the horizontal must be limited, the design can be based on exactly the same principles as outlined in the first part of the paper and applied to the open road beam. The horizontal distribution of intensity in the beam must be further modified by the fact that as the maximum candle-power is limited to between 1 deg. and 2 deg. below the horizontal plane the range of visibility, due to the driver's own lamp, cannot be more than about 100 ft. Thus the horizontal and vertical distribution below the horizontal plane for the pass-lamp should be similar to that proposed for the City beam.

Beam Specifications.

In Fig. 16 the City beam is combined with the anti-dazzle requirements above the horizontal plane to give a form of beam specification suitable for use on British roads. This may be compared with the provisional standard American "Lower beam" which is given in Fig 17. Several important points of difference are im-

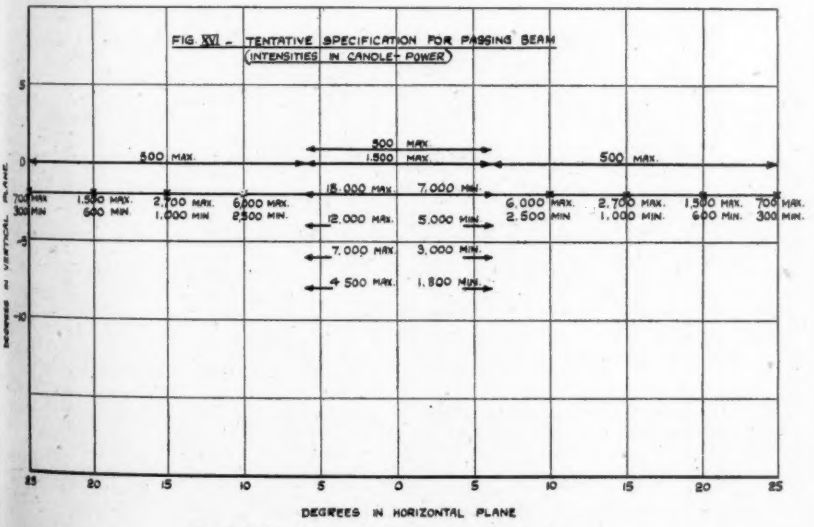


Fig. 16. Tentative specification for passing beam.

mediately evident between the two beams. The American beam is not symmetrical about the vertical plane containing the axis of the lamp, as it throws more light to the nearside, and especially is this so just above the horizontal plane. This design has not been adopted in the form of beam suggested for use in this country as it is felt that (a) the tortuous nature of many British roads make it undesirable to allow more than the minimum candle-power above the horizontal even in directions in which it should nominally be innocuous, and (b) the provision of adequate candle-power below the horizontal and on the offside will serve to accentuate the visibility of objects seen by silhouette.

In the American specification considerable freedom has been allowed to the designer in the choice of the horizontal distribution, a course which is desirable since the more complex conditions to which the beam must conform cannot be so clearly stated as in the case of the open road beam.

In comparing the beam specified in Fig. 16 with that in Fig 17, it must therefore be borne in mind that the former illustrates one example of a passing beam, whilst the latter is intended to cover a selection of beams by different designers.

Comparision of these two specifications with a typical example of European practice can be made by noting the difference in permissive candle-power between the previous figures and the specification given in Fig. 18. It can be seen that the candle-power towards the approaching driver's eye is in this case much reduced, but at the expense of a very much greater loss in the power of the beam below the horizontal plane. Often the maximum candle-power of such beams was only a little above the statutory minimum; and, even in cases where a higher candle-power was attained, the beam spread was necessarily narrow because of the low luminous output of the bulb, an essential of the Bilux anti-dazzle system. This is exemplified in Fig. 19, where the horizontal distribution of such a Bilux passing beam is compared with that specified for the City beam. The exponents of this method of dazzle prevention have overstressed the importance of providing comfortable conditions to a dangerous extent as visibility is

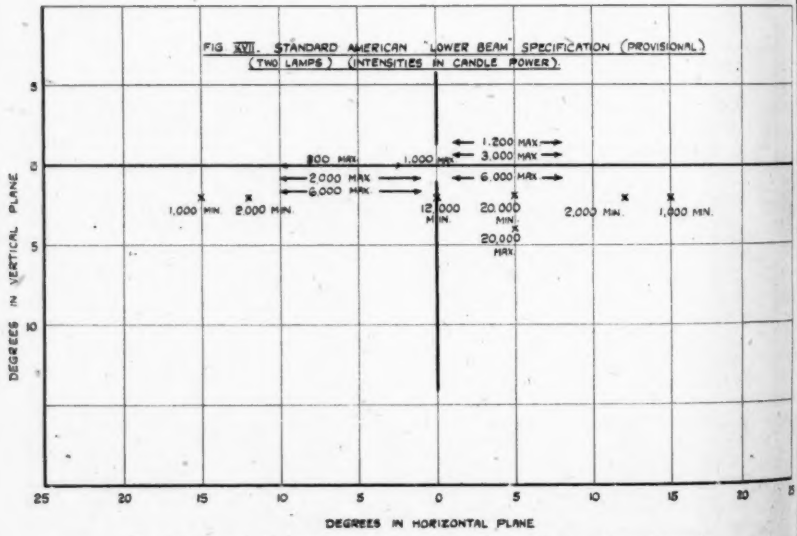


Fig. 17. Standard American "Lower Beam" specification (provisional).

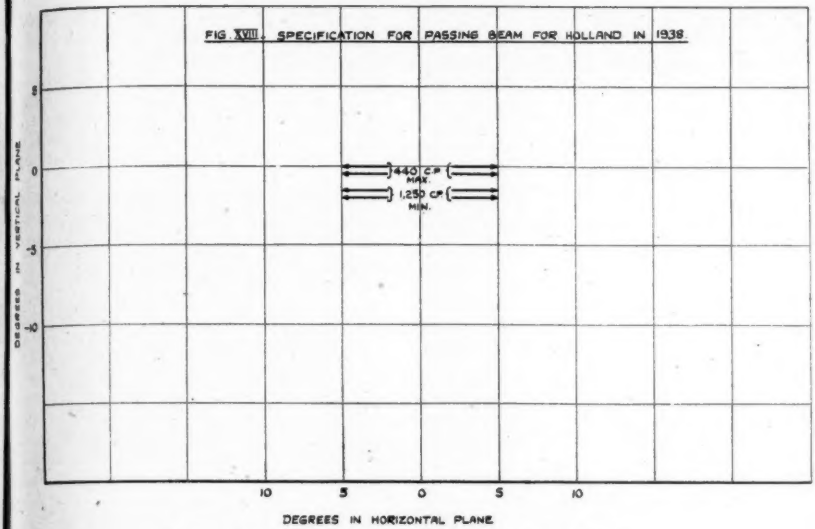


Fig. 18. Specification for passing beam for Holland in 1938.

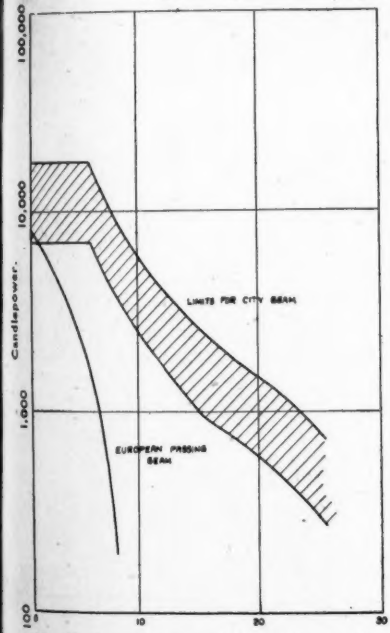


Fig. 19. Comparison of "City" beam with "European" passing beam.

definitely lower than, for example. given by the American beam (4).

Lamp Setting

Careful consideration of the specifications shown in Figs. 17 and 18, and also of the pictorial representation of the vertical distribution shown in Fig. 8 will make it quite evident that if lamps made to such designs are to be used to the best advantage, their setting on the vehicle must be carried out with care. It has previously been pointed out that in aiming the lamp and choosing the distribution in the region of the beam axis that the smoothness or otherwise of the riding of the vehicle must be taken into account. Allowance for transient errors in aiming is to some extent simplified by the fact that, on the whole, the lamp will be aimed too high as often as it is aimed too low.

Should the lamp be incorrectly aimed when the vehicle is at rest, this last assumption will not be valid, and the illumination given by the lamp will not be that intended by the designer.

The importance of correct aiming in the case of pass-lights cannot be too

highly stressed, and it is probably no exaggeration to say that of all the factors contributing to the production of dazzle on the roads to-day the maladjusted lamp is the most serious. It is for this reason that, whilst the driving beam must also be aimed properly, the aiming problem is one that is best dealt with in relation to pass-lamps.

The aiming problem can be analysed into the following subdivisions:—

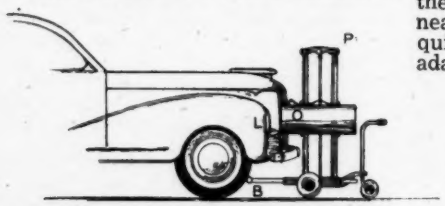
(a) The design of suitable equipment or aids which indicate when the beam is properly adjusted.
(b) The provision of suitable means for adjusting the lamp on the vehicle.
(c) The carrying out of the necessary adjustments to the lamps under conditions of vehicle loading similar to those under which the vehicle is to be used.

Apparatus for the Garage

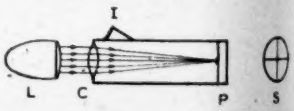
Equipment for setting of lamps falls naturally into two classes, the first comprising the type of apparatus which the vehicle manufacturer and the service garage would use, and the second, devices which the motorist himself might purchase and carry for his own benefit. Of the former class of equipment a number of examples have been made available in America and more recently in France. Some of these pieces of equipment are very elaborate and costly, but the principles used in each case are the same. A condensing lens is arranged with a screen in its focal plane, and the beam from the headlamp is allowed to fall on the screen and its position adjusted until it is either symmetrically placed with respect to markings on the screen or the adjustment may be facilitated by the use of photo-electric cell which is connected to an instrument calibrated in candle-power. In the latter case, the lamp is set so that the maximum candle-power of the beam is directed towards the photo-cell. The axis defined by the condensing lens and the photo-cell or markings on the screen is positioned accurately with respect to the track of the vehicle. In one instrument this is achieved by means of a horizontal bar carried about 3 inches above the ground and arranged to be at right angles to the axis of the optical system. The apparatus is positioned relative to the vehicle by locating the bar against the front tyres, and the optical system can be moved vertically on slides so designed as to allow it to remain fixed in any position. The action of this instrument is shown diagrammatically in Fig. 20 and the photograph in Fig. 21 shows that the instrument can be readily brought to the vehicle, which is a point to be considered if the space in the service garage is restricted.

Portable Apparatus

The type of apparatus used by a service garage is obviously quite unsuitable for use by the motorist himself, both on the grounds of cost and of bulk. For the motorist a compact unit is required, and it should be such that it can be put in the pocket of the car. So far as the writer is aware, no such apparatus has, as yet, been marketed. The police photometer used for checking the wartime headlamp mask is the nearest to the type of apparatus required, and this could be easily adapted to serve as a peace-time aid to



(a) General view of equipment being used.
L, Headlamp being aimed.
O, Optical system.
B, Bar resting against tyre.
P, Pillars carrying optical system.



(b) Sectional view of optical system showing paths of light and type of aiming screen.
L, Headlamp.
C, Condensing lens.
P, Photo-cell.
I, Instrument calibrated in candlepower.

Fig. 20. Headlamp setting device for garage use.

the motorist by the inclusion of a steel measuring tape by which the height of the cell above the ground could be measured. When using the apparatus the motorist would first measure the height of his headlamp from the ground, and then walk about five paces down the road in front of the

Fig. 21. Lamp setting equipment for garage use.

car, and using the tape to position the photo-cell correctly he could observe whether the maximum intensity in the beam was directed above or below the horizontal. A laboratory model of such an apparatus is shown in Fig. 22, and with this apparatus an accurate setting of the lamp is practicable.

R.A.C. Disc.—The use of specialised equipment is not essential for the accurate setting of lamps, although it may greatly facilitate it. One of the most useful devices for observing whether or not a lamp is properly set is the R.A.C. disc. This consists of a disc, about 12 in. diameter, mounted on an upright post and arranged so that its height can be adjusted. The circular disc is first brought to the same height as the headlamp, and then the upright is carried some way in front of the vehicle, and the pattern of the beam intercepted on the disc can be observed. The setting of the lamp is greatly helped by such a device, which can be easily made by the handyman.

Fig. 22. Portable lamp photometer.

Lamp Mounting

The aiming of a pair of headlamps is not an operation which the driver can do once and then forget them. As a rule, lamps will not require readjusting often once the car is run in, but whilst the suspension is settling down the setting should be periodically checked. Again, if the loading is abnormal it may be desirable to reset the lamps specially for that journey. Because of this it is essential that the mounting of the lamps should be such that the driver can make the adjustment easily, a requirement which is particularly important for the pass-lamp, since the driver must aim this accurately in order to relieve other drivers of glare, and will not do so if the aiming is a difficult or tedious operation.

The Importance of the Motorist's Co-operation

It will be evident from the foregoing that the heart of the dazzle problem lies not only in the design of a suitable beam but also in the correct understanding and use of the equipment by the motorist. Perhaps the most serious misconception that exists is that there is a kind of lamp that gives an inherently non-dazzling beam, and that once such a lamp has been fitted the driver is absolved from further responsibility. This idea is very popular, and, as it appeals to the indulgence of the lazy man, is not likely to die without a struggle. It is, however, the duty of the lamp designer and manufacturer to ensure that all purchasers of lamps appreciate that it is the way in which a lamp is used that renders it non-dazzling,

and that the lamp is always used by the motorist, who must finally take the responsibility for its proper functioning.

Since this paper is concerned primarily with the fundamental principles of vehicle lighting, it may, at first sight, appear somewhat out of place to discuss the user's reaction to the equipment. It must, however, be remembered that dazzle is a subjective phenomenon and does not exist except in the presence of a user. Moreover, the circumstances of the case are such that the efficacy of the method adopted depends entirely on the good will and understanding of the motorist. Finally, it is usual for not only motorists but competent engineers to treat the dazzle question as if it were intimately associated with black magic, instead of being perfectly simple and straightforward—at least, as far as appreciating what happens, if not in finding a solution.

PART III.

Movement in Fog

The inconvenience caused by fog is not confined to vehicle drivers, but is as important to those engaged in any form of transport. In fact, to the sailor or airman it is a matter of very great moment, since once he has embarked on a journey he must carry it through; it is therefore of paramount importance that means should be available to enable the navigator either to penetrate or avoid fog zones.

The study of meteorology has reached a very advanced state, and it is now possible to predict the time of onset of mist and fog with some degree of accuracy. The work which was carried out in order to achieve this state has resulted in a vast accumulation of knowledge as to why fog reduces visibility, the nature of fogs, and the behaviour of light in mists and fogs, but has not resulted in any panacea for the evils of fog.

Nature of Fog-Visibility.

On the practical side, the examination of the appearance of objects seen through mist shows that the contours remain perfectly sharp, even when their visibility has fallen to zero due to the reduction in contrast caused by the veiling effect of the fog. It may, in fact, be said that fog causes practically no blurring of the contours of objects, and thus nearly all the reduction in visibility is caused by the scattering of light other than from the objects themselves. This is exemplified by the superior visibility of self-luminous objects, the beacon being always the last resort for route marking.

Scattering of Light by Small Particles.

Much theoretical work has been done on the scattering of light by water and other particles, and this work has been related to the practical weather observations by meteorologists. The most important fundamental information that is required is a quantitive description of the nature of the scattering of light by water particles of various size. The results of some recent work (6) on this subject are shown in Fig. 23. Incident light is supposed to be coming from the left-hand side of the diagram and the curves show distribution of the light scattered, the radial scale being logarithmic. The curves are drawn for increasing values of the ratio $2a/\lambda$, where $2a$ is the drop diameter and λ the wavelength of the light. It can be seen that when the drop is small compared with the wavelength the intensity of the scattered light increases very rapidly with the drop size, and is nearly uniform in all directions round the drop. As the size of the drop is increased the proportion of light scattered towards the source falls, but that scattered forward continues to increase in the same manner, namely with the sixth power of the drop diameter.

There are two important lessons to be learnt from these measurements: (a) when light is scattered by a mixture of small and large particles only the characteristics of the latter need be considered, (b) when light is scattered in directions other than forward by large particles the wavelength of the incident light will not be of great importance.

Relation Between Theory and Practice.

Field experiments on the visual range of objects illuminated by different coloured lights confirm the latter

finding. The results published by Foitzik [7] relating the relative extinction coefficients for red and blue lights with the visual range show that when the visibility is high (say above 10 miles) red light is advantageous, but when the visual range is below 1 mile there is no significant difference between the results for red and blue light. The relation between the visual range and the significant drop size is quite evident if one compares the field measurements showing the visual range and the relative extinction coefficient with the relation between the relative extinction coefficient and the drop size. Figs. 24 and 25 are taken from Foitzik's work and show a remarkable agreement between field and laboratory findings.

The sizes of the fog particles can be measured directly, as can mist and cloud particles. In country districts and at sea, the particles are nearly pure water, in all cases it is found that, as expected, the fogs contain a number of large particles. In cities, the fog particles contain a relatively large concentration of dissolved substances such as sulphur dioxide, which have the effect of decreasing

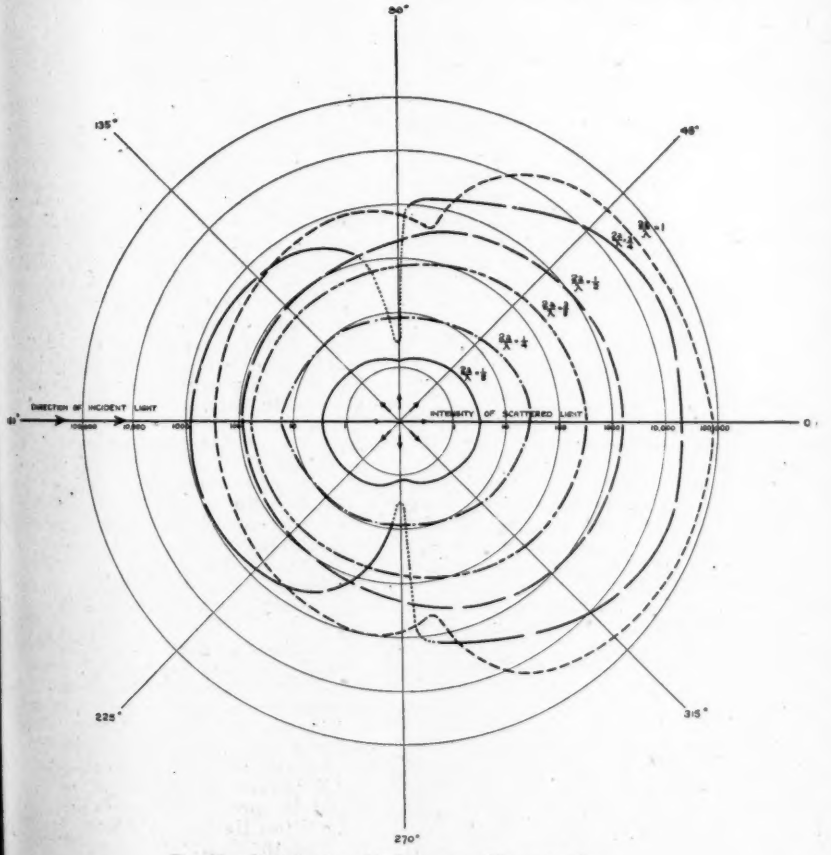


Fig. 23. Distribution of light scattered by water drop.

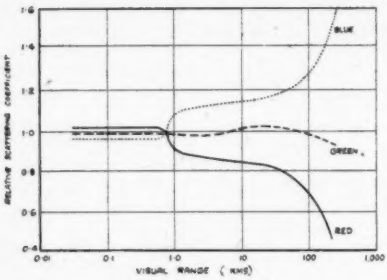


Fig. 24. Relation between visual range and the scattering coefficient for different wave lengths.

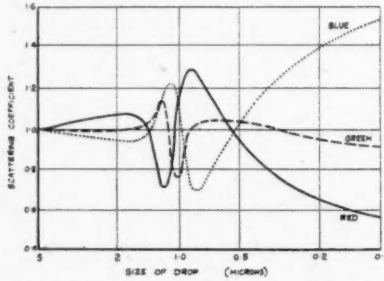


Fig. 25. Relation between size of drop and the scattering coefficient for different wavelengths.

the vapour pressure in the vicinity of the drop, and thus hindering evaporation and dispersal of the fog.

Aids to Movement in Fog.

The object of the study of the weather is, at present, limited to prediction of future weather conditions, of which the visibility is an important factor, and is not concerned with alleviating the plight of those inconvenienced by these conditions, except by directing their movements towards places where the effects can be avoided. Such a solution is often of help to the ship and aeroplane, but is no use to the city motorist wishing to reach his surburban home on a foggy evening.

The motorist is, in fact, only partially interested in a fog warning. Generally, he cannot suddenly decide to go home two hours earlier, but he does want to be provided with a safe passage through both mist and fog. The mariner is also in a similar position, and because of his somewhat different circumstances the available means of alleviating the deleterious effects of poor visibility are far greater.

Radio.—If a liner is fog-bound as it approaches port, the cost in lives and money may be very large, so that the cost of the solution is not a major consequence. Furthermore, equipment could be bulky and, owing to the slow movement of the ship, a short delay in interpretation of the information provided would not be of great consequence. Under such circumstances the use of radio-location and a continual scanning of the ship's surroundings could be developed to allow safe movement. The wartime developments in this field have been so extraordinary that there seems every reason to suppose that position finding by radio should enable a big ship to manoeuvre and berth by means of radio alone. Aircraft can be guided to their landing strips with great precision, but this is a slightly different case since two radio stations are involved.

In the case of the automobile the method of blind landing which has been developed for the aircraft would not be suitable because it virtually places the vehicle on rails and does not take into account other road users. There is a somewhat closer connection between the car and the ship; in fact, the only difference is the speed relative to the surroundings which causes the motorist to demand a very much more speedy response. The use of radio to enable vehicles to move in safety is probably rather far-fetched at the moment, but the technical developments have recently been so far-reaching that it cannot be dismissed as impossible.

Coloured Light.—The most popular solution offered to the motorist is the coloured glass filter which is supposed to change the nature of the white light given by this lamp. The results quoted above show quite conclusively that in a dense fog, or even mist, this solution is in reality no help to the motorist at all. Thus it may be stated that if visible light is to be used to enable movement in fog, white light should be preferred, or, to be quite correct, the light should not have its wavelength distribution modified in any way. Thus yellow light is suit-

able if the source is a sodium vapour lamp, but white light is to be preferred if an incandescent lamp is used.

Practical Fog Lighting

Using visible light there are three main aids to movement under fog conditions:—

(a) Specially controlled fog lamps giving a fan beam, so designed as to reduce scattered light towards the driver.

(b) Beacons marking salient points on the route.

(c) Reflex signs, excited by the vehicle's own lamps, but acting as self-luminous sources.

Of these it is essential to realise that the lamp enabling the driver to see unexpected obstructions is by far the most important. The beacons and reflex signs may be an enormous help, but they have the strictly limited function of marking the route and do not enable the driver to see unexpected obstructions.

The design of the fog-lamp beam must take into account the following requirements:—

(a) Objects in the path of the vehicle must be silhouetted against a uniformly bright haze.

(b) The light distribution must be such that light scattered towards the driver should have suffered two or more scatterings.

To achieve this the beam must obviously be confined to a comparatively few degrees above and below the horizontal plane.

(c) The distribution of the beam in the horizontal plane should be such that the reflex signs on the road margins are evenly illuminated. In this connection it is particularly important that the signs near the vehicle should be illuminated in dense fog.

The type of horizontal distribution suggested for the City beam would provide a suitable basis for the fog beam. The vertical distribution should, however, be entirely different from those suggested for other purposes. The majority of the flux should be confined to the region of the horizontal plane and lie within a zone about 3 deg. deep. The most important factor of all is the control of light at large angles to the horizontal plane. Both above and below this plane the stray light should be reduced to a minimum.

Maintenance.—In the section dealing with pass-lamps the importance of correctly aligning the lamp with respect to the vehicle was stressed. The aiming of the fog-lamp is, of course, important, but of even greater significance is the maintenance of the lamp in good condition. The efficiency of the fog-lamp depends very largely on the reduction of stray light to an absolute minimum. If the maximum candle-power of a fog-lamp is about 20,000 c.p. and the candle-power at 60 deg. above the horizontal is 5 c.p. when the lamp is clean and in good condition, then an increase in the upward light to 30 c.p. or 40 c.p., resulting from a deposition of dust or water drops on the front glass, will cause a very considerable reduction in visibility.

To maintain the required distribution it is essential that the lamp designer uses the simplest possible optical system, and also ensures that the interior of the lamp is clean. The user's task is in many ways more difficult since he must ensure that the outside of the lamp is scrupulously clean, under atmospheric and road conditions which naturally tend to deposit a layer of dirt on the front of the lamp.

Conclusion

In the foregoing account of the problems of motor vehicle lighting, an attempt has been made to indicate how headlamps may be designed from principles similar in many respects to other lighting problems. The choice of beam distributions has been shown to be based upon theoretical considerations which have been developed in conjunction with practical experiments over a number of years. So far the treatment has not been advanced far enough to stand critical examination from a purely theoretical standpoint. It has, however, proved an immense help in guiding the course of experiments, and for this reason alone its publication seems amply justified.

The peculiar problems of dazzle and fog have been examined, and the best compromise offered in each case. Both problems remain unsolved, although polarised light may in time

offer a solution for dazzle. In both cases the importance of the user's care in aiming and maintaining his lamp in the way the designer intended has been stressed. In fact, it would not be an exaggeration to say that the dazzle problem rests mainly in the hands of the user, who is now provided with equipment which should enable the dangers of dazzle to be very nearly eliminated. The situation in the case of fog is unfortunately not so far advanced, though the use of reflecting road studs throughout long stretches of main road will undoubtedly prove a great benefit.

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DISCUSSION

THE PRESIDENT said the subject of motor-car headlamps would be a serious one after the war when, it was to be hoped, there would be a great improvement in the technique of lighting and the facilities for driving. He had taken a good number of tests some years ago on various anti-dazzle fittings, mostly of American origin, but we did not seem to have made much progress since then as regards the solution of this problem.

DR. W. S. STILES said that Dr. Nelson had given a most interesting account of the problems of headlight illumination and of the methods he was using in the design of headlamps. In the past, a good deal of scientific work had been done on these problems and a good deal of advice had been offered to those most concerned, but with meagre results. It was therefore particularly gratifying to hear a physicist in the industry attacking some of those misconceptions which it had appeared hopeless to try further to remove. Thus Dr. Nelson advocated a passing beam in which both maximum and minimum candle-powers were specified in the most important regions of the beam—in effect, he advocated a standard beam with certain tolerances. He implied, if he did not actually say so, that the standard beam should be universally adopted. This was a great step forward. The light had been seen. Where next might it not penetrate?

For the open road beam, Dr. Nelson aimed, firstly, at making the road uniformly bright, and, secondly, at equalising the residual non-uniformity and the time variations which arise from the oscillations of the car, etc. Dr. Nelson's theoretical derivation of the ideal beam he was unable to follow and he would rather judge by results. Taking the ideal beam, what was the variation of road brightness in the vertical plane containing the headlamp axis, and how closely did time variations balance the non-uniformity? Dr. Nelson suggested that an upper limit to the intensity of the open road beam was imposed by back-scatter in the atmosphere. He (Dr. Stiles) had difficulty in accepting this. There was experimental evidence for thinking that if the distribution of the light was unchanged any practical increase in beam intensity would improve the visibility of objects.

In discussing dazzle, Dr. Nelson used the glare formula to deduce that dazzle was independent of the distance apart of the cars. This was a fair deduction only if attention was confined to a point object on the axis of the driver's own headlamp. In fact, however, the jay walker just stepping off the curb was an equally important object and the effect of dazzle on the visibility of this object certainly increased as the cars approached. It seemed to him, therefore, that the rather flat curve (Fig. XIV.) derived by Dr. Nelson to show how visibility distance changed with the c.p. of the headlights gave a wrong picture of the dazzle situation.

To take another point, this same jay walker was an object which might not be made visible by silhouette against the bright patch of road produced by the reflection of the headlights of the approaching car. He might step into the road when the bright patch had passed him. The silhouette effect had of course been recognised by earlier workers on headlight dazzle but it had not been relied on because, as just noted, it did not always operate. He thought Dr. Nelson might be right in laying greater weight on this factor.

The suggested passing beam seemed very reasonable but it would be useful to

have some quantitative assessment of its performance compared with other beams. It might be of interest to apply to it the methods of appraisal put forward by Dunbar and himself in 1935.* Had Dr. Nelson made any examination of this kind?

The idea of linking the open road and passing beams so that they were aligned together seemed a very good one, as it went to the root of one major difficulty in the dazzle problem.

Dr. J. W. T. WALSH said that, having had an opportunity of reading the paper he must confess to a feeling of disappointment at the way in which the author had treated his subject. He did not agree that discomfort glare necessarily produced disability. There had been cases of discomfort glare in which, at any rate for a limited time, the ability to do a task did not appear to have been affected at all, but that would probably not apply over a long time. Incidentally, he said he wished writers of papers on illumination would always use the internationally agreed symbols of E for illumination and I for candle power. The present author had not done this and so had made it rather less easy to follow the mathematics in the paper.

He could not follow the author's argument where he purported to produce a beam to give a certain theoretical distribution, and he could not see the basis upon which the author derived the curve given in one of his earlier figures. Apparently the author based his theoretical treatment on the illumination produced on a number of planes normal to the line of sight and deduced some conclusions based upon the variation of illumination with small departures of the axis of the beam from the theoretical horizontal position. Then, at the bottom of page 4, the author suddenly equated two integrals, but it was difficult to understand why these integrals should be equal. In fact, further on, the author introduced a constant n, which seemed to be entirely at his disposal. He did not see how the author arrived at the conclusion he did arrive at except by a purely arbitrary method, in which case he might have cut out the mathematics altogether.

At a further stage, the author suddenly switched from the vertical to the horizontal plane and got into three dimensions. He failed to see how the original equations could possibly apply in that case, and he suggested that the theoretical treatment at the beginning of the paper should be made clearer or withdrawn altogether.

Mr. A. TWIDLE said that the Government at the moment was very interested in mitigating dazzle. There seemed to be an impression that under the present conditions of masked headlamps the dazzle problem had been eliminated, but his own view was that dazzle had actually been increased. The paper helped considerably by exposing the number of misconceptions on the part of motorists and the general public. The sole consideration was the reduction of road accidents, and therefore a car must be provided with a safe driving light, and that dazzle was really a secondary consideration. The author, however, had left out of consideration the general public and had looked at the matter rather from the angle of the motorist himself. A pedestrian could be dazzled and walk into a tree or some other obstacle due to dazzle from a masked headlight, and if it were admitted that it was impossible to prevent dazzle under all conditions, then, if there was to be a driving light without too much dazzle, it was probable that certain regulations would have to be formulated. At present there was no law which compelled a motorist to dip his lights under any particular circumstances, and it would be very difficult to frame a regulation to cover this point. He asked for the author's view as to the best position for the headlight, because at present they were fixed at varying heights, with the result that drivers can be dazzled from the lights on certain classes of vehicle. There were four points to be considered, viz.: (1) the employment of a properly designed lamp controlled to give a specific performance; (2) the uniform positioning of lights on all vehicles; (3) the trim of the lamps; and (4) the education of motorists to use any improved passing light scheme which can be developed. It should be possible to devise lamps which would conform very closely to the definite specifications and which would provide the type of beam that was most suitable for the correct illuminating of the road and the object. The author had pointed out the possibilities here of a fixed

* "The valuation of glare from motor car headlights." Technical Paper No. 16. Illum. Res. Com. Depart. Sci. Indust. Research, H.M. Stat. Office.

focus type of lamp which could not be tampered with. It would also be interesting to ascertain what were the best positions for the headlights and passing lights to give the best results under average road conditions, bearing in mind that road surfaces were not absolutely level and also the fact that the effect of road corrugations might be troublesome to the driver if the lights were positioned too close to the ground.

With regard to the trim of the lamps, he was rather frightened by the complicated optical arrangement shown by the author for checking the setting of lamps. The trouble was that it was not so much the initial trim of the lamp which presented difficulty, but that from time to time the lamp would become out of adjustment due to variations in load and dip of the springs. The driver would therefore have to be provided with an easy means of checking the trim of his lamps and of adjustment at any given time.

It would take some time to educate the motorist to use passing lights correctly, and as regards polarised light, he felt that again the author had omitted to consider the pedestrian and the cyclist, because for polarised light to be of any value to them they would have to be provided with analysing spectacles. Better street lighting should be provided in towns and many improvements were possible in this field.

Mr. T. J. SACK said that a Ministry of War Transport Committee was at present investigating the problem of the motor-car headlight, and expressed his agreement with the previous speaker when he said that the driving light was more important than anti-dazzle qualities. More accidents were caused through bad headlights than through dazzle, and statistics published in America showed that 60 per cent. of fatal accidents were caused at night time, in spite of the fact that there was only one-third of the traffic on the roads. Curves had also been published showing that more fatal accidents happened in rural than in urban districts, again demonstrating that bad lighting is responsible. He hoped we should not fall into the same trap here as had been the case in America of devising anti-dazzle regulations without thinking carefully of the driving light. Something would have to be done in the way of compelling the motorist to *use*, as well as fit, some anti-dazzle arrangement; the absence of any compulsion to use the device was one of the weaknesses of the earlier regulations. He believed there were great possibilities with polarised light, and the fact that the driving light was affected rather considerably had been over-emphasised. If dazzle could be eliminated it would not be necessary to have so much driving light for safety. He had seen headlamps fitted with polarised light, and they were most effective. He also doubted whether the effect of the camber of the road was as bad as had been stated. Probably really efficient street lighting was the real solution. Before the war there were some three million vehicles on the roads in this country, each having generating equipment of an average value of, say, £10. Quite a lot of public generating plants could be installed for £30,000,000 for lighting the highways in a manner which would reduce the number of accidents considerably. He had seen it suggested that every car should have a photo-electric cell fitted on the front which, when activated by the lights of an approaching car, would automatically switch off the driving lights and switch on the passing lights. This would have the advantage that drivers would be relieved of switching responsibility. To be acceptable it would have to be compulsorily fitted to all cars. The photo-electric cell would also be activated by good street lighting and would prevent the annoyance caused by thoughtless drivers who persist in keeping their headlights on in brightly-lighted thoroughfares.

Mr. H. S. ALLPRESS welcomed the reading before the Society of such a paper as the present valuable contribution by Dr. Nelson. In his view the subject was essentially one of illuminating engineering and should be approached from that angle in the first instance.

He suggested that the problem should be regarded as a special case of street lighting and the main desiderata to obtain the maximum overall disclosing power with an arrangement of low-mounted directional lamps (including lamps directed against the traffic flow) established separately from and before considering the specification for the power and light distribution of headlamps. The paper, however, did not seem to him to be developed strictly on this basis, and gave an impression that it was rather a justification for headlamps of existing conventional design or of types which could readily be made commercially available.

Mr. Allpress went on to state that he

could not follow the use of the symbol "n," which as $\frac{\Delta\theta}{\Delta\phi}$ was apparently given quite arbitrary values in the equations. When regard was taken of the magnitude of the angles involved (bearing in mind the practical difficulties of setting and the angular movement of the axis of the car due to pitching or uneven loading) it would seem to him to invalidate the precise finite values given for the "ideal" beams as developed from the mathematical arguments in the paper and shown as almost radial curves to logarithmic ordinates.

It would also appear that Dr. Nelson's arguments would have more weight if he extended still further on a mathematical basis his statements in support of what appeared to be a basic contention —that "normal" illumination to give even brightness over the whole field of view was the main criterion. It was not obvious that this would ensure the maximum brightness contrast with vertical objects in all possible positions on the road surface—such as pedestrians in wet (and shiny) light clothes.

With regard to the diagram showing the effect on visual acuity of an approaching car with similar headlamps, it would be helpful if the term "visibility distance," in the sense used in the paper, was defined more clearly. It was far from obvious that this gave a direct measure of the true disclosing power of the lighting arrangement.

In view of the sharply defined nature of the beams some doubt seemed to arise that the optimum visibility would occur with the candle power indicated, as no account seemed to be taken of the actual intensity directed towards the eye of the driver. Except at long ranges this was likely to be much less than the maximum beam candle-power and the diagram only referred to distances up to 30 ft. At longer ranges the contrast provided by objects behind or a short distance in front of the approaching car (i.e., not silhouetted by road surface illuminated by the lamps of the latter) would be important and call for a specially high degree of visual acuity not negatived by glare.

Mr. Allpress remarked that, after the many years during which attempts have been made to design a non-glaring headlamp, a consideration of the illuminating engineering principles involved now showed that the glare problem was mathematically insoluble without some deflection of the driving beams during the passing period unless visibility during normal driving was to be sacrificed. In fact, Dr. Nelson's paper confirmed his impression that an "ideal" glareless beam cannot even be visualised quite apart from the practical considerations of providing it. In any event any so-called non-glaring passing beam for continuous use was not likely to be popular in this country, and would be "meddled with" by users.

The Continental traffic codes seemed to accept this. The mandatory requirement to reduce speed as well as switching to a "passing" beam had much to recommend it, and from his experience seemed to work well in practice.

Mr. R. MAXTED agreed with Dr. Stiles that it should be possible to have 100,000 c.p. before running into limitations due to back scattered light, even in an English atmosphere. It should be borne in mind that the atmosphere in many countries abroad was appreciably clearer than in this country, and users there may have a genuine requirement for the higher candle-powers thus rendered practicable—for example, on mountain roads where fatal accidents may occur if the edge of the road falls below the threshold brightness.

As regards effective administrative action, he recalled that suitable regulations were enforced in New Zealand many years ago, and accepted in the common good by a people who were fond of personal liberty. The driver was made responsible for having his headlamps properly adjusted and periodically checked. Public garages were equipped in a simple and effective manner, a grid of lines being drawn on a vertical wall, and headlamps adjusted at a distance 30 ft. or 40 ft., so that the maximum candle-power was below the horizontal. He believed the regulation was then that headlamps must *not* be extinguished while the car was in motion outside a city area, and that only dipped headlamps were permissible within a city area.

With improved optical designs available or practicable to-day, such regulations should offer a reasonably effective solution. He suggested that if flat-topped beams were to be adopted, then the arrangement of road signs should be reviewed. Mounting heights of the order of 10 ft. would be excessive, as we have good reason to know after some years' experience of A.R.P. headlamp masks.

Communicated:—

Referring to the work of the I.E.S. and B.S.I. Committees on A.R.P. headlamp masks some years ago, I believe I then urged that reduced intensities above the

horizontal should be permitted—say 10 per cent. to 20 per cent. over 3-4 degrees. The argument was that this graduated cut-off would reduce the effect of the peculiarly disconcerting intermittent glare arising from the pitching of an approaching car, and that it would reveal road signs, especially "Halt" signs, of the reflector type. The kinematical factor would also apply to passlights, even though road signs were placed at more suitable heights.

Mr. W. H. LUND welcomed the paper as indicating progress since pre-war days, when some dipping arrangement was the only form of anti-dazzle device available. Indeed, he was pleased to see that there was no mention in the paper of this device. The author had referred to illumination 100 ft. ahead, but this distance—only 33 yards—appeared quite insufficient. It was a question of mounting height on the vehicle. The pass light could be at an even higher level than the headlamp. If the eye was above the cut-off level it would not be affected by dazzle, and a distance of 150 to 200 ft. was practicable.

Dr. J. H. NELSON in replying to the discussion stated that he was of the opinion that the universal adoption of a passing beam specification was desirable. In answer to the points raised by Dr. Stiles, Dr. Walsh and Mr. Allpress, he explained that in deriving the distribution of intensity required from a headlamp he had assumed that the road surface and road margin were composed of a large number of elementary planes all lying normal to the incident light. It was necessary to adopt some such device because it has been found that if the road surface is treated as a horizontal plane then the reflection factor varies with the angle of incidence and yields values greatly exceeding unity. The work published by Dr. Stiles was quoted.

Dr. WALSH said that the high reflection factor occurred from the viewpoint of the on-coming motorist and not from the point of view of the man behind the headlight.

Dr. J. H. NELSON disagreed with this and expressed the opposite point of view.

Dr. STILES said that he and his co-author, in their 1937 paper, obtained very high apparent reflection factors because they measured from behind the headlamp on the ordinary road and used the apparent reflection factor in order to work back from the illumination to the road brightness. They measured the road brightness and divided it by the computed horizontal illumination and so got a high value, which might be very much the same as the author suggested. The reflection factor was simply a way of getting back to the brightness from the illumination.

Dr. NELSON, continuing, stated that his treatment of the distribution of brightness in the field of view had been based on the assumption that in the static case the field should as far as possible be so illuminated that the brightness was uniform. At the same time the distribution of intensity from the lamp should be so chosen that when used on a moving vehicle, and thus subject to periodic deviations from its correct aiming direction, the brightness changes in the field should be reduced to minimum. To reduce the changes in brightness due to movements of the vehicle it was necessary to sacrifice the uniformity of brightness of the static case. The author had assumed, arbitrarily, that the non-uniformity of brightness in the static case should be approximately the same as the changes in brightness caused by the motion of the vehicle and has expressed this equality by equation (3) of the text. This equation was also the source of the parameter "n," which was in practice the ratio of the semi-angular subtense of the field of view in any direction to the average angular movement of the lamp axis in the same direction. The parameter was therefore determined by the practical conditions in each case and was not quite at the author's disposal.

The author had chosen the limit of 100,000 c.p. because it had been found by experience that the back-scatter became distracting at about that intensity. No doubt the effect was due to the driver being distracted and not due to a reduced visible range. He did not wish to propose the limit as a hard and fast rule, but experience indicated that such a limit existed.

The use of circularly polarised light was, as Dr. Stiles suggested, the solution to the problem of critical setting of the analysis if polarised light were used to alleviate glare. Experience so far indicated that it would be necessary.

In reply to Dr. Walsh concerning glare, Dr. Nelson stated that it was not

his intention to imply that discomfort was proof of disability, but if one experienced continuous discomfort it would lead to disability. With regard to other road users and the whole question of dazzle and polarised light, pedestrians and cyclists could use spectacles and he did not see why they should be too expensive. On the whole, the important thing to realise was that the motorist must see, and it was better that other road users should be dazzled than that they should be killed. The most important matter was that these other road users should be seen by the motorist.

A SPEAKER asked about the possibility of other road users making unpredictable movements.

Dr. NELSON agreed that the position of other road users had to be considered, but did not foresee any greater difficulty in this particular respect than previously experienced, though possibly some control of headlamps might be necessary in urban areas. It would, however, be interesting to observe the results of the American experiments to which the speaker had referred.

With regard to Mr. Twidle's fears about the complicated lamp setting jig, the author could state that such a jig had proved very simple to use.

While agreeing with Mr. Sack that more accidents were due to lack of light than to dazzle, he reminded him that the electrical equipment of a car was not solely to supply the headlamps, so his argument in favour of universal street lighting was not financially sound.

In using the term visibility distance, the author had been quoting from the work of Roper, and the distance referred to that at which a pedestrian in dark clothing could be seen by a driver who was not expecting to meet an obstacle. In the author's opinion such a criterion was the most suitable for judging the revealing power of headlamps. In carrying out any investigation it was found by experience that a crude measurement taken from a moving vehicle was more valuable than the most elaborately planned research under static conditions.

In reply to the speakers who had mentioned anti-dazzle lamps and their enforced use by legislation, the position could be summarised by saying that a driver could tolerate only about 500 c.p. towards his eye, but needed approximately 10,000 c.p. to see about 100 ft. in front of his vehicle with comfort and safety. For a beam to achieve this when mounted on a modern car with a relatively soft suspension it was impossible to give a visibility distance of more than 100 ft. This limitation was determined by the simple geometry of the problem and could not be stretched. Such a beam, whilst admirable for passing, was totally inadequate for driving. Moreover, if the best results were to be achieved some standard of mounting height should be aimed at. For the majority of vehicles 2 ft. 6 in. from the ground would be satisfactory, though this might be rather low for large commercial vehicles.

It was clearly desirable to legislate for a driving and a passing beam, and the following form of legislation had been suggested by the Society of Motor Manufacturers and Traders, which was for immediate introduction and could later be followed by a more specific definition of a passing beam:—

1. All vehicles may use, at one time, either one or two lamps giving a main driving beam or beams for road illumination. The maximum luminous flux emitted by the filament lamps used in the headlamps giving the main driving beam shall not exceed 1,000 lumens for each lamp.
2. When approaching another mechanically propelled vehicle a driver shall not use his main driving beam, but shall use one authorised passing beam.
3. An authorised passing beam is given by one lamp so fitted, maintained and used, at all times that the illumination given at a distance of 10 feet from the lamp on a vertical surface at or above the height of the centre of the lamp does not exceed 15 foot-candles.
4. The passing beam must fulfil the above requirement under all conditions of loading, and when the vehicle is standing on a level road with the engine running at such a speed that the dynamo is charging and the discharge load consists only of the ignition, obligatory lights, and the lamp giving the passing beam.
5. In the event of a vehicle not being fitted with a lamp designed to give an authorised passing beam, it is possible to fulfil the conditions of paragraphs 3 and 4 by suitably setting a conventional headlamp, but it must be recognised that the best permissible driving light will not thereby be achieved.

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